Hydrologic Analysis of the Kitts Hummock Area

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Introduction

The community of Kitts Hummock, DE has become prone to frequent coastal storm flooding problems. To understand the causes of the flooding and ways to improve drainage the Delaware National Estuarine Research Reserve was asked by the Delaware Department of Natural Resources and Environmental Control, Division of Soil and Water Conservation to examine the hydrology of the area. To achieve this analysis a comprehensive water level monitoring network was established around the community. As part of the study, key questions posed by the residents of Kitts Hummock were addressed. These residential concerns, besides the overall hydrology, included the interconnectivity between the marsh north and south of Kitts Hummock Road, the effects of the Ted Harvey Wildlife Area impoundments on the adjacent marsh, the effectiveness of the tide gate, and whether the drainage network influences the open water areas in the marsh.

Description

Kitts Hummock, Delaware is a small coastal community east of Dover, DE. The community of less than 100 homes is located on an attached barrier beach with marsh and areas of open water to the west (Figure 1). Access to the community is via Kitts Hummock Road, which in certain locations is within a few feet of the marsh on either side. The watershed to the north of Kitts Hummock Road extends to Dover Air Force Base to the west, and north following Pickering Beach Road. This watershed is drained through Lewis Ditch, south of Pickering Beach. A previously maintained waterway, Sand Ditch, occasionally connects the watershed with the Delaware Bay, but continued maintenance of the ditch was suspended and Sand Ditch currently has intermittent drainage to the Delaware Bay. The Lewis Ditch watershed is 14.4 km^2 (3560 acres). Approximately 400 meters south of Kitts Hummock Road across open marsh is the Logan Lane impoundment of the Ted Harvey Wildlife Area. This impoundment, that was constructed in the 1960's, modified the watershed south of Kitts Hummock Road. This new watershed of less than 0.5 km^2 (122 acres) was drained by a ditch network south of the community and flowed into the Delaware Bay. In 2003 a self regulating tide gate was installed to allow for tidal flushing of the marsh while still limiting flooding from storm surges. If the tide gate is not functioning properly, or at flow capacity, excess water must exit to the north towards Lewis Ditch. There are historic ditches throughout the marshes, originally installed for mosquito control, but currently only the ditch south of Kitts Hummock Road, 75 meters west and paralleling South Bay Drive, leading to the tide gate is maintained. The marshes north and south of Kitts Hummock Road, referenced as Northern Kitts Hummock Marsh (NKHM) and Southern Kitts Hummock Marsh (SKHM) are primarily privately owned.

Methods

To perform the required monitoring a network of 8 Onset HOBO water level recorders were installed to be used in conjunction with the USGS tide gauge located approximately 5 kilometers (3.1 miles) south on the Murderkill River at Bowers Beach and a meteorological station located at the Delaware National Estuarine Research Reserve (DNERR), 3.5 kilometers (2.2 miles) to the west (Figure 2). Two water level recorders were placed on the north and south sides of Kitts Hummock Road in the primary north/south drainage ditch approximately 250 meters (820 ft) inland from the Delaware Bay, this was believed to be a location of a pipe under the road connecting NKHM and SKHM. These two recorders provided an accurate estimation of the water levels in the marshes alongside Kitts Hummock Road. Two recorders were placed in the open water areas of NKHM to examine any backwater effects from the upper watershed or storm surges north of Kitts Hummock Road. An additional two water level recorders were used to examine any interrelationships between the SKHM water elevation and the northern impoundment of the Ted Harvey Wildlife Conservation Area, with a recorder placed in each open water area. A fifth water level reorder was installed along the main drainage ditch along South Bay Drive, approximate 150 meters (500 ft) from the tide gate. A final recorder was housed at the DNERR to measure barometric pressure in order to atmospherically correct the readings of the water level recorders. The recorders were surveyed to an accuracy of ± 2 cm (0.4 in) vertical. The units recorded water level every 12 minutes and were maintained and downloaded bi-monthly by staff from the DNERR.

Delaware Bay water levels were retrieved from the United States Geological Services (USGS) tide gauge at the mouth of the Murderkill River at Bowers Beach. The levels are recorded every 6 minutes and transmitted via satellite to a USGS website where they are accessible for downloading. The gauge has a datum of 0.0 NGVD29 and therefore an offset of -0.24 meters was applied to conform with the NAVD88 datum used in the project.

Rainfall amounts were measured by the DNERR meteorological station with a tipping bucket rain gauge. The gauge has a resolution of 0.254 mm (0.01 inch) and records rainfall in 15 minute intervals.

After the monitoring began it was determined that additional data of the flow through the tide gate would be beneficial to the project. An Isco 4150 Area-Velocity module was installed in the tide gate and connected to a an Isco 6712 portable sampler for data recording. The flow data was collected at 2 minute intervals.

Monitoring Period

Installation of the equipment and collection of data began on June 3, 2009 at sites 3-7. The recorders were installed at Sites 1 & 2 on June 8 after obtaining landowner permission. Site 6 was temporally removed between July 31 and August 6 to allow for ditch maintenance. Water level data retrieval stopped on August 25 at sites 1 & 2 and on September 1 at site 5 due to possible hunting conflicts on private land. Active collection was stopped on September 14 at the remaining sites, however all units are still in place and recording data with approximately 6 months of internal storage available. The tide gate flow monitoring equipment was installed on July 14 and removed on September 14.

During the monitoring interval there were two extended periods when less than 2.5 mm (0.1 in) of rainfall occurred on any given day, which provided good background condition values. In addition there were 4 events when more than 25.4 mm (1 in) of rainfall including events of 89 and 99 mm (3.5 and 3.9 in). There were also two coastal storms that caused elevated tide levels in the Delaware Bay.

Interpretation of Data

Murderkill River - Bowers Tide Gauge Error

The Murderkill River - Bowers tide gauge maintained by the United States Geological Survey (USGS) was used as an indicator of the Delaware Bay water level off shore of Kitts Hummock since the gauge is only 5 km (3 mi) south of the community. When analysis of the data began, discrepancies in the values emerged. A series of surveys were performed over a 6 hour period by staff from the Delaware Coastal Programs which found tide values to be approximately 0.35 meters lower than what was reported (Figure 3). After contacting other agencies it was discovered that researchers from the Delaware Geological Survey had found an error of 0.34 meters for the gauge, and surveys of high water marks after the 2008 Mothers Day storm by DNREC's Division of Soil Water revealed values around 0.35 meters less than what is reported by the USGS data.

Conclusion

The local tide data reported for the Murderkill River at Bowers Beach gauge is incorrect. The data is reported in an antiquated datum (NGVD29) and is higher than the actual tide level by approximately 0.35 meters (13.5 in). To convert the data from reported NGVD29 feet to the currently used NAVD88 and correct for the error the value must be reduced by 0.55 meters (21.6 in).

Watershed Surrounding Kitts Hummock

The extent of watershed around Kitts Hummock has changed over the years due to the construction of the Ted Harvey Wildlife Area impoundment (THWAI) and the intermittent nature of Sand Ditch. Since Sand Ditch is not a consistent outlet for surface water, the watershed was calculated using Lewis Ditch, South of Pickering Beach, as the watershed outfall. Originally this watershed would have encompassed the area north to Pickering Beach Road, west to the Dover Air Force Base and south to Kitts Hummock Road. The total area of this watershed is 14.4 km^2 (5.6 mi^2). Runoff south of Kitts Hummock Road prior to the 1960's would have flowed south to the St. Jones River, however that changed when the levees surrounding THWAI were built. The area between Kitts Hummock Road and the THWAI can either be considered a separate watershed with an outfall through the tide gate or part of the larger northern watershed, when the water level is above the road. The area of the southern watershed is only 0.5 km^2 (0.2 mi^2) and contributes only an additional 3.3% to the total area of the combined watershed area (Figure 4). Of these 2 sub-watersheds the southern watershed is approximately 0.32 km^2 (0.14 mi^2) marsh, while the watershed north of Kitts Hummock Road contains over 3.6 km^2 (1.4 mi^2) of marsh.

Conclusion

While the extent of the watershed surrounding Kitts Hummock increased with the construction of the THWAI in the 1960's this additional area accounts for less than a four percent increase in area. Most of this increase is in marsh surface and does not have the potential to greatly increase water flow into the marsh from upland surface runoff. While data has shown evidence of runoff water entering the NKHM, the amount of water level rise is similar between NKHM and SKHM due to the lag time in the water reaching the marsh allowing for drainage from the NKHM to the Delaware Bay.

Kitts Hummock Road Elevation

Using LiDAR data with an average accuracy of 15 cm (6 in), a transect was taken along the length of Kitts Hummock Road. The results indicated three extended sections of the road are at an elevation of less than 1.2 m (3.9 ft) NAVD88 (Figure 5). Two of the sections are located where the old drainage ditches meet the road. The third location is the longest and lowest, about 150 m (500 ft) of the road prior to the intersection with Bay Drive. This area has approximately 75 m (250 ft) that is below 1.1 m (3.6 ft) NAVD88.

<u>Conclusion</u>

During times of coastal flooding when the NKHM water level exceeds 1.1 m (NAVD88) water will begin to cross Kitts Hummock Road. If the level exceeds 1.2 m NAVD88 several sections of the road will flood. Initial flooding will begin at the intersection of Kitts Hummock Road and N/S Bay Drive, isolating a majority of the residences from a safe evacuation route. During times of extreme flooding high ground would be 1.2 km (0.75 miles) inland. During the Mothers Day storm of 2008 the water elevation around Kitts Hummock was documented at 2 meters NAVD88; 1 meter (3.3 ft) above Kitts Hummock Road at N/S Bay Drive.

Connectivity between NKHM and SKHM

Analysis of data between Sites 3 & 4, which are located within 10 meters (33 ft) of each other on either side of Kitts Hummock Road initially showed no similarity in water levels. In June the water level difference ranged from 0.031 to 0.085 meters (1.2 to 3.3 in) higher in NKHM. In July the levels varied independently with time and SKHM had the higher level. During the last week of August, workers from the Delaware Department of Transportation uncovered the pipe under Kitts Hummock Road. The water levels on either side of the road then became identical. Rainfall events showed a temporary higher level in NKHM but the levels would equalize in a few days. The 99 mm (3.9 in) rainfall on September 11 & 12 caused a level difference between the 2 sites of 0.09 meters (3.5 in) with minimal level convergence after 2 days (Figure 6).

After an extended period of dry weather in July, Sites 1 through 5 reached a common water level. This equilibrium was again achieved on other occasions before rainfall events caused the levels to disparately change. This equilibrium level slightly decreased throughout the monitoring period.

Conclusion

There is a pipe under Kitts Hummock Road at Site 3/4, however the pipe is not of sufficient size to be useful for drainage. After the 89 mm (3.5 in) rainfall of August 22 it took six days for the NKHM and SKHM levels to come to equilibrium and it is probable that most of the level decrease from NKHM was due to drainage to the north and not transport through the pipe since the SKHM level did not rise to meet the NKHM levels.

The marsh water levels react separately to rainfall or overwash events, but given time, they will reach a common level. This implies that this equilibrium elevation is the level of the groundwater table for the area, which typically decreases slightly over the summer months. The dissimilarity of the equilibrium water level in the Ted Harvey Wildlife Area Impoundment can be explained by a possible combination of altered soil porosity values due to impoundment construction and/or manipulated level control through the water control structures.

Marsh Drainage Rate

Water levels after storms were analyzed to determine the maximum drainage rate from each of the marshes. The maximum rate for NKHM, that was not during times of dune overwash back to the Bay, took place between June 28 to 30. During this period the NKHM water level decreased at a rate of 4.2cm/day (1.65 in/day) The maximum drainage rate for the SKHM, measured at Site 4, was 2.5cm/day (1.0 in/day) on September 12. This maximum rate of the SKHM rate occurred after the South Bay Ditch and tide gate were cleaned. The flow rate recorded by the instrument mounted in the tide gate measured an outflow of 13,000 m^3 (455,000 ft^3) on September 12, which based on the marsh area and the location of recorders are within acceptable rates of agreement with water level changes. This was also a time of neap tide allowing for maximum time for flow out of the tide gate.

The marsh water levels were also examined during extended periods of dry weather. Drainage rates during two dry events are shown in Table 1. The NKHM had a higher drainage rate during both periods with Site 2 being significantly higher than Site 1. Further examination of the data showed that the water level at Site 2 was 5 to 7.5 cm (2 to 3 in) higher than Site 1 indicating drainage of the southern open water in NKHM to the northern open water. SKHM had water level changes of only 0.5cm/day (0.2 in/day). Review of literature on marsh evapo-transpiration (ET) rates suggest a maximum ET rate of marsh surfaces to be around the 0.5 cm/day rate.

Conclusion

The maximum observed drainage rate of the NKHM is approximately 4.2 cm/day (1.6 in/day) when the water level is below the dune line. The water drains to the north and exits either through Sand Ditch, depending on its functionality, or further north to Lewis Ditch. The northern areas of NKHM drain quicker than the southern sections of NKHM due to the limited hydraulic connection between the two. SKHM, under optimal conditions, will drain at a rate of 2.5 cm/day (1.0 in/day) through the tide gate. Optimal conditions include a fully cleaned and operational tide gate, clean inflow trash screen and neap tide. If the water level of the marsh is above Kitts Hummock Road it is expected that the majority of the water will exit to the north towards Lewis Ditch unless there is a breach in the dune that allows for drainage from another location.

SKHM Tide Gate

A Doppler flow recorder was installed in the tide gate on July 14, 2009. Initial data from the reorder was poor due to the abundance of silt in the tide gate enclosure and high amount of debris flowing through the structure. After the South Bay Drive ditch and the tide gate enclosure were cleaned in early August reliable data was obtained. Flow values during periods of limited rainfall revealed a net inflow to the SKHM from the Delaware Bay during spring tides and a net outflow during neap tides (Figure 7). The mean flow rates for these periods were 1100 m^3/day (39,000 ft^3/day) spring tide inflow and 1300 m^3/day (46,000ft^3/day) neap tide outflow. The maximum recorded outflow of 13,000 m^3/day (455,000 ft^3/day) took place on September 12 during a neap tide after 10 cm (3.9 in) of rainfall.

Conclusion

The tide gate installed at the outfall of the South Bay Drive ditch, under normal conditions provides the marsh with limited tidal flushing as designed. Under optimum conditions, in a flood event, enough water could flow through the tide gate to lower the water level in SKHM approximately 25 cm (1 in) per day. These optimum conditions include a neap tide, clean trash screen on the tide gate inlet, clean tide gate enclosure, and a debris free South Bay Drive ditch.

SKHM Marsh Water Levels Affected by Ted Harvey Wildlife Area Impoundments

When monitoring began the water level in the open water area of SKHM was approximately 0.05 meters (2 in) higher than in THWAI . Between June 10 and June 21 the levels were similar in each location. On June 22 the weir level of THWAI was lowered causing a drop in the water level until June 29. During this time the water level in SKHM did not decrease. On July 1 the water level difference was 0.135 m (5.3 in). By the end of the July the water level in THWAI was 0.19 m (7.5 in) lower than SKHM. In August the water level in THWAI averaged over 0.21 m (8.2 in) lower than SKHM (Figure 8).

Conclusion

Minimal hydraulic connection exists between SKHM and THWAI. It would be logical to assume some connection exists through the groundwater aquifer, however, the porosity of the subsurface sediments is too low to provide for equalization of the water levels inside and outside of the impoundment. This low porosity could be attributed to compaction of the soil during impoundment construction and from repeated drying cycles due to water level management.

Rainfall Contributions to Marsh Water Levels

Rainfall events showed clear changes in the marsh open water levels. Figure 9 illustrates these changes for two late summer storms. When a series of rainfall events were analyzed, water level changes between NKHM, SKHM and THWAI varied slightly but were not significantly different. An average increase in marsh open water area equivalent to 1.4 times the amount of rainfall was shown, however the time to reach the highest level is longer for NKHM indicating a lag time for runoff from the upper reaches of the watershed to reach the marsh (Figure 10).

Conclusion

Rainfall events will raise the water elevation in the open water areas of NKHM, SKHM and THWAI by approximately 1.4 times the rainfall amount. There is a longer lag time in NKHM to peak levels caused by runoff water from the upper watershed.

Other Possible Factors Controlling Water Surface Elevation and Extent

After extended dry periods all open water areas, except THWAI, reached a common water elevation, indicating some hydraulic connection between the sites. This common level could possibly be attributed to the elevation of the surficial groundwater aquifer. Installation and monitoring of groundwater piezometers would be required to verify this assumption. The Bowers Beach area has a documented subsidence rate of over 4.0 mm/yr (0.16 in/yr) coupled with global eustatic sea level rise of 1.6 mm/yr (0.06 in/yr) resulting in a combined sea level rise of 5.6 mm/yr (0.22 in/yr). If anthropogenic activities have limited the necessary sediment input derived through flooding events, the marsh surface may not be able to keep pace with the rising sea level through natural accretion processes.

Conclusion

The base water level in NKHM and SKHM is probably controlled by the upper level of surficial aquifer rising above the land surface elevation. Over the past 50 years the relative sea level around Kitts Hummock has risen approximately 28 cm (11 in), which would in turn raise the surficial aquifer adjacent to the Bay. Local land subsidence, diminished accretion rates, and global sea level rise would be an explanation of expanded open water areas and increased marsh areas documented in historic photos.

South Bay Drive Drainage Ditch Maintenance

During the first week of August the South Bay Drive ditch was cleaned and bottom elevation lowered in the process. Before maintenance, the lowest water level recorded at Site 6 was 0.528 m NAVD88 after maintenance the lowest water level recorded was 0.280 m NAVD88. The upper water levels due to tidal inflow remained constant. The level of the open water area of SKHM (Sites 4, 5) did not show any noticeable change pre and post maintenance activities (Figure 11).

Conclusion

Ditch maintenance in SKHM does not substantially affect the open water areas of the marsh. It does increase tidal flushing in the immediate vicinity of the ditch system. It is important that the ditches are kept clean and functioning to provide free flow of water to the tide gate inlet and prevent debris from accumulating on the trash screen.

Coastal Storm Flooding

Over the course of the study period there were two coastal storms that caused a series of spikes in the water levels of NKHM. The changes in water level at Site 1 during these storms were sudden and occurred with the high tide(s) (Figure 12). These abrupt changes in water level at Site 1 corresponded to a gradual increase in water level at Sites 2 and 3. The spikes at Site 1 occurred when the Bowers - Murderkill tide gauge recorded corrected values of approximately 1.1 meters (3.6 ft) NAVD88 or 5.5 ft uncorrected gauge output.

Conclusion

Flooding of the Kitts Hummock marshes occurs when Delaware Bay water levels exceed approximately 1.1 m NAVD88. The flooding originates north of the community of Kitts Hummock in the vicinity of Sand Ditch. Sustained periods of high tidal levels in the Bay will provide sufficient overwash for the flood waters to proceed southward to the southern half of NKHM. If the water level in NKHM exceeds the elevation of Kitts Hummock Road, then SKHM will begin to flood. The estimated over dune flooding elevation will change due to the dynamic nature of the dunes and Sand Ditch.

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Figures

and

Tables

Figure 1. Kitts Hummock, DE

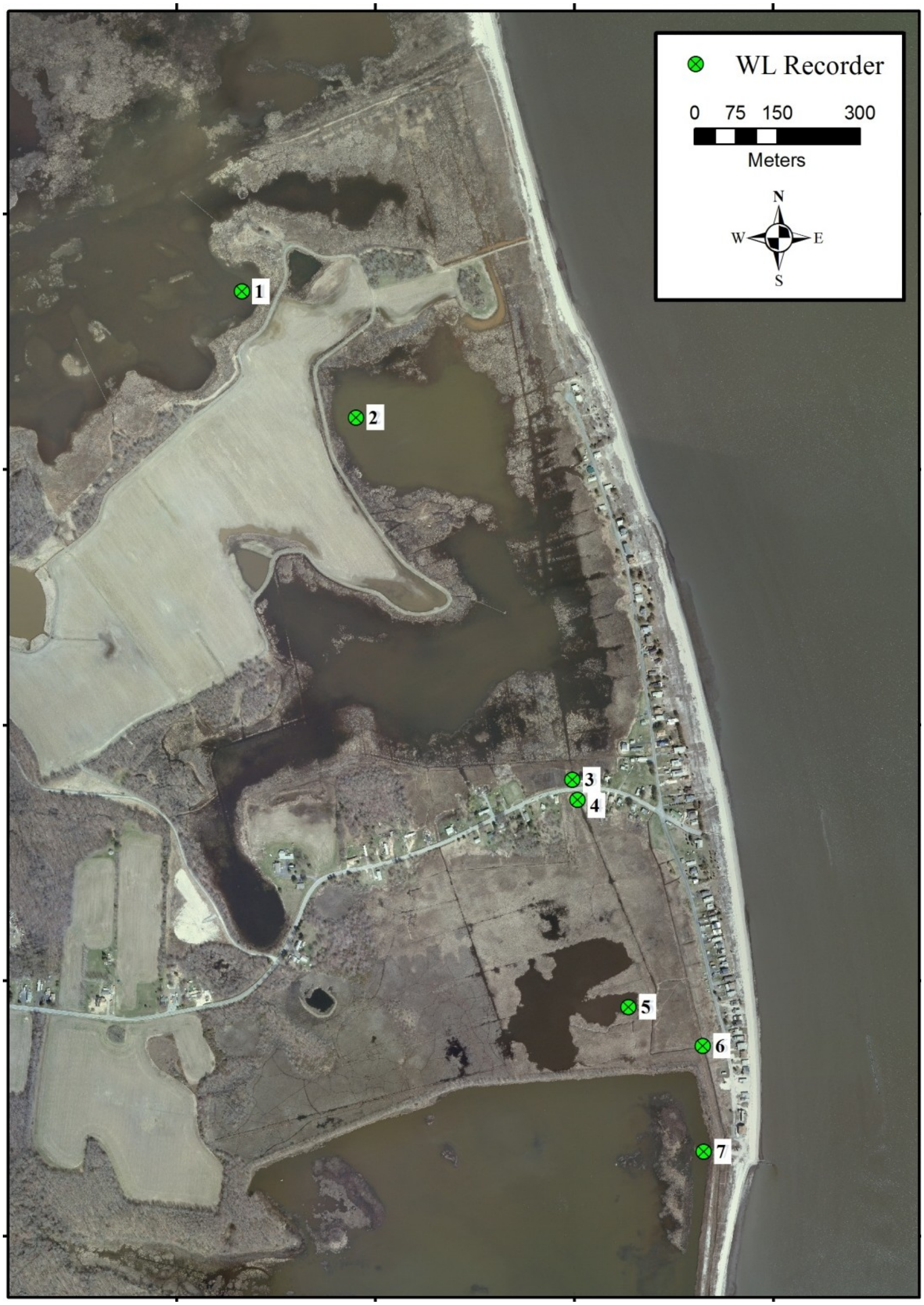


Figure 2. Locations of water level recorders.

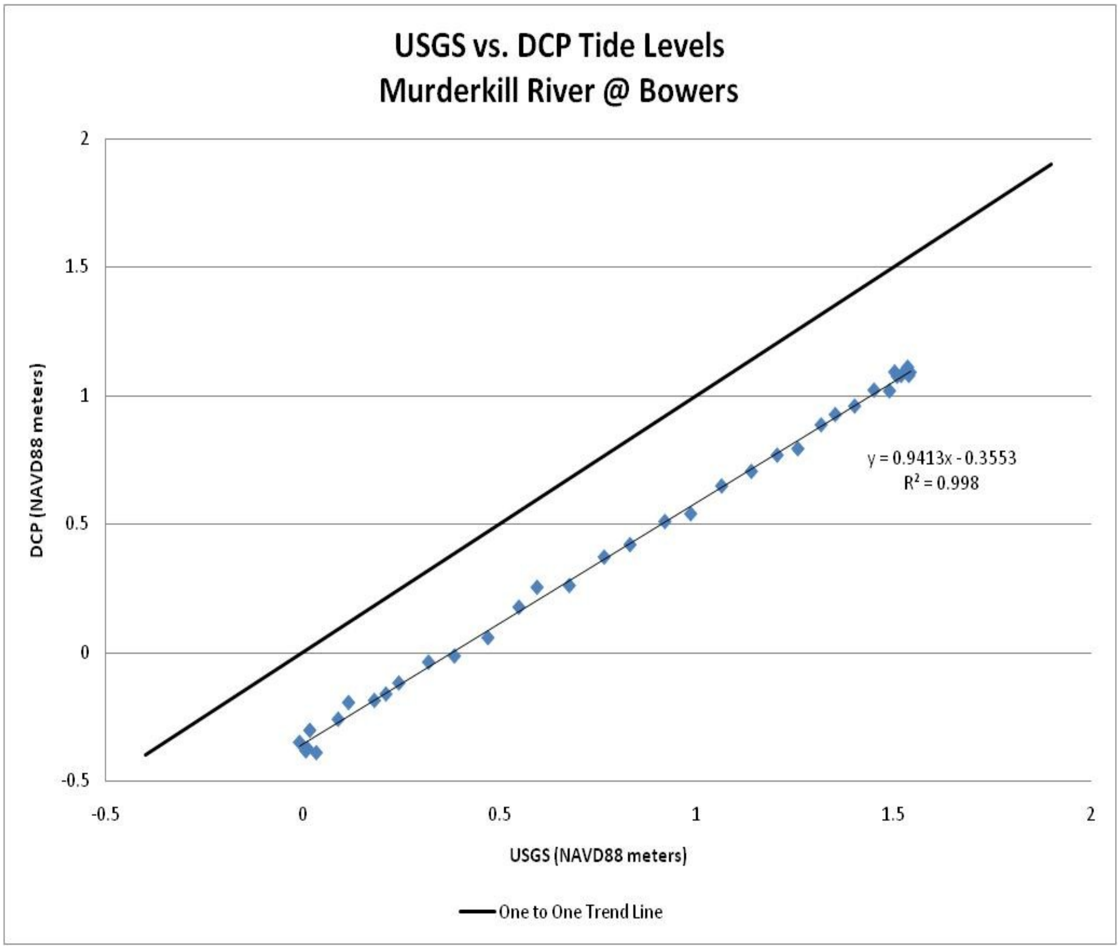


Figure 3. Comparison of tide levels between USGS gauge and DCP survey.

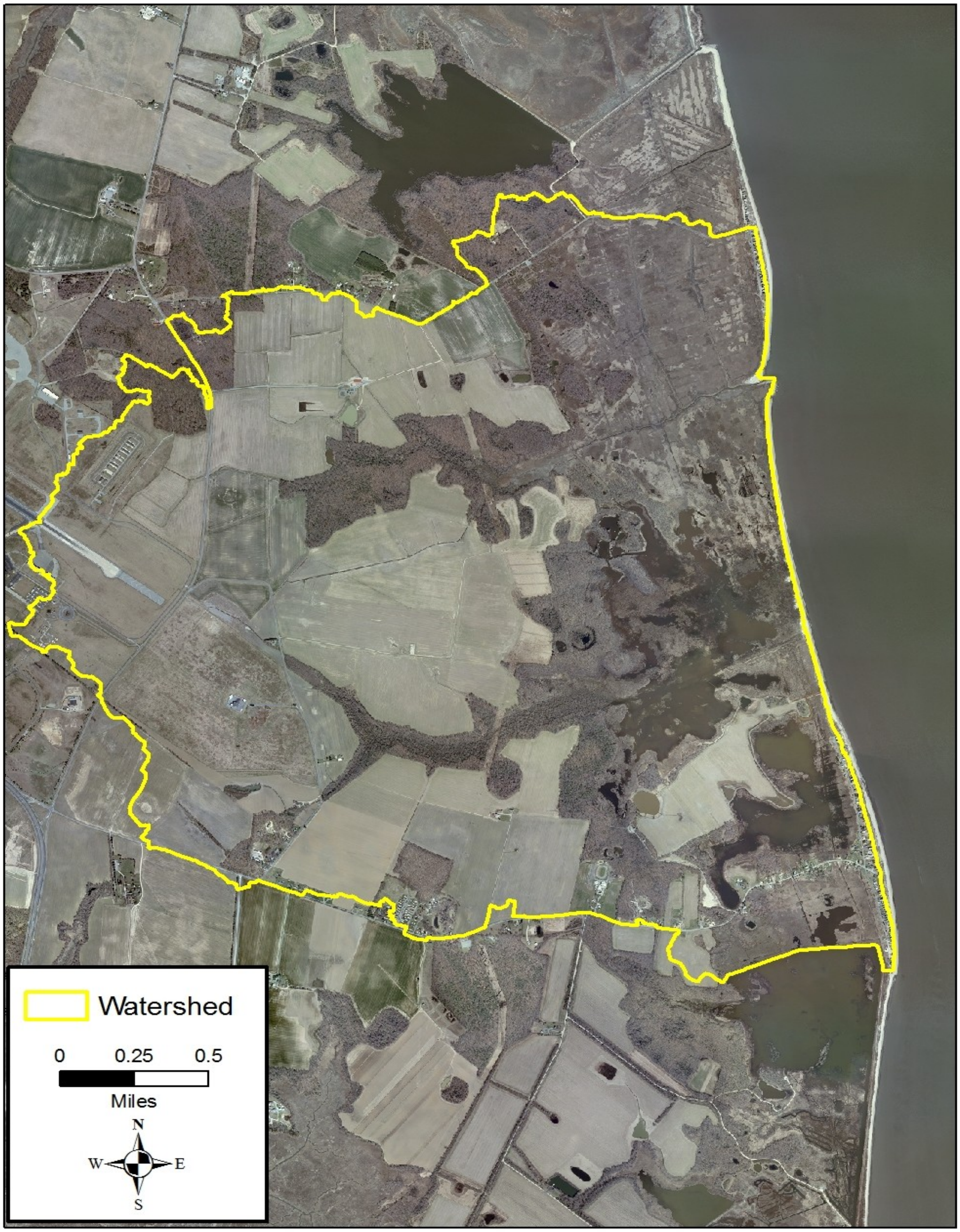


Figure 4. Watershed surrounding Kitts Hummock, DE.

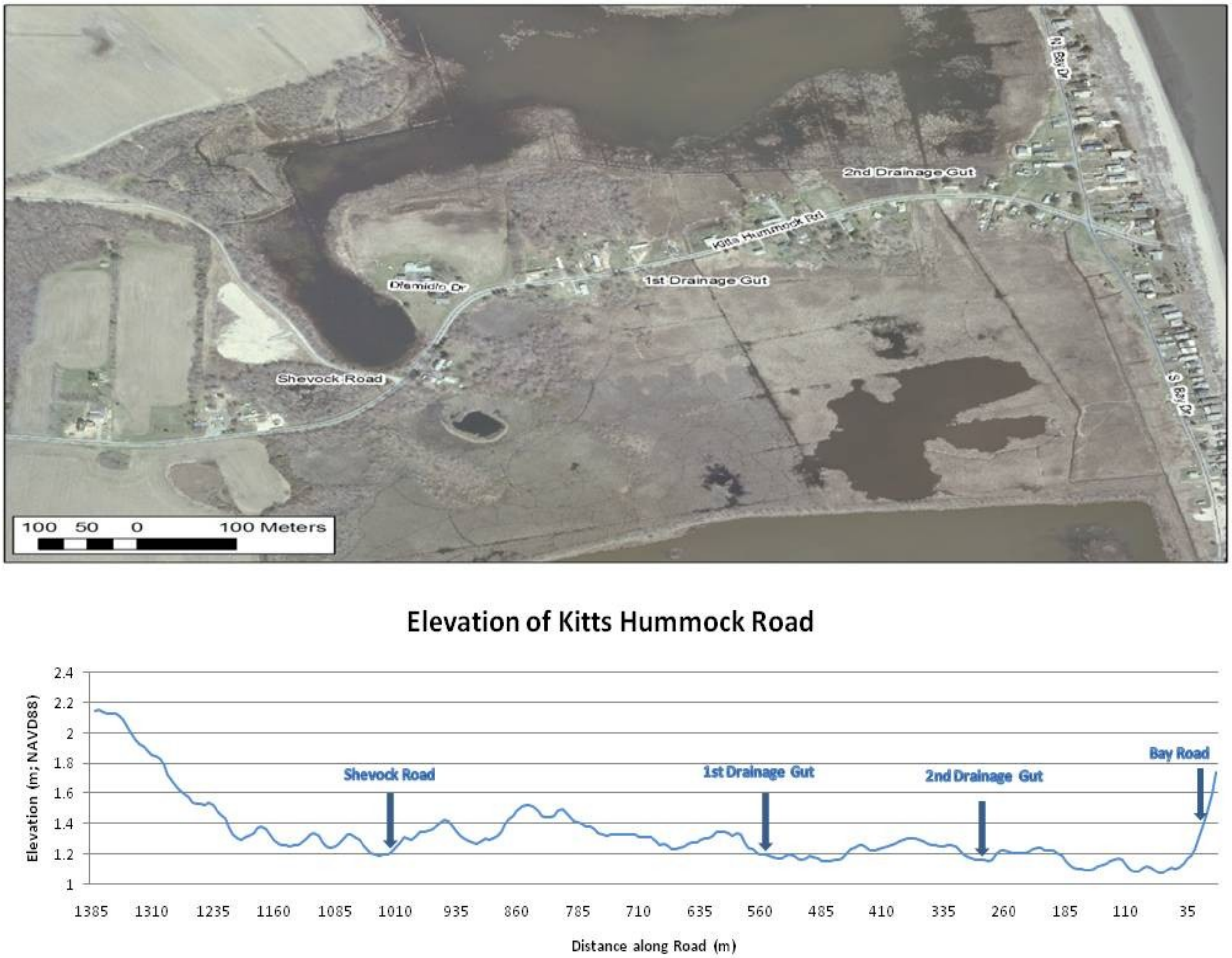
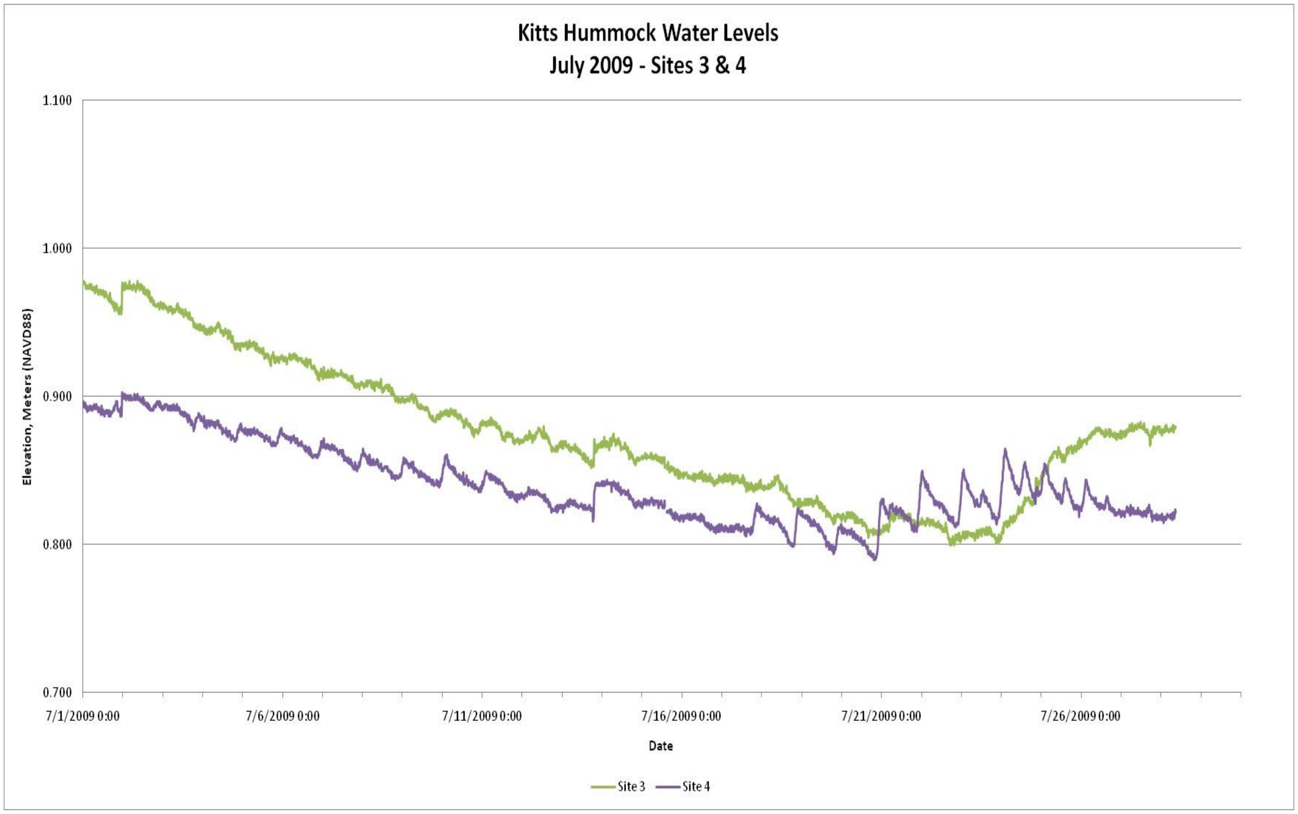


Figure 5. Elevation along Kits Hummock Road.



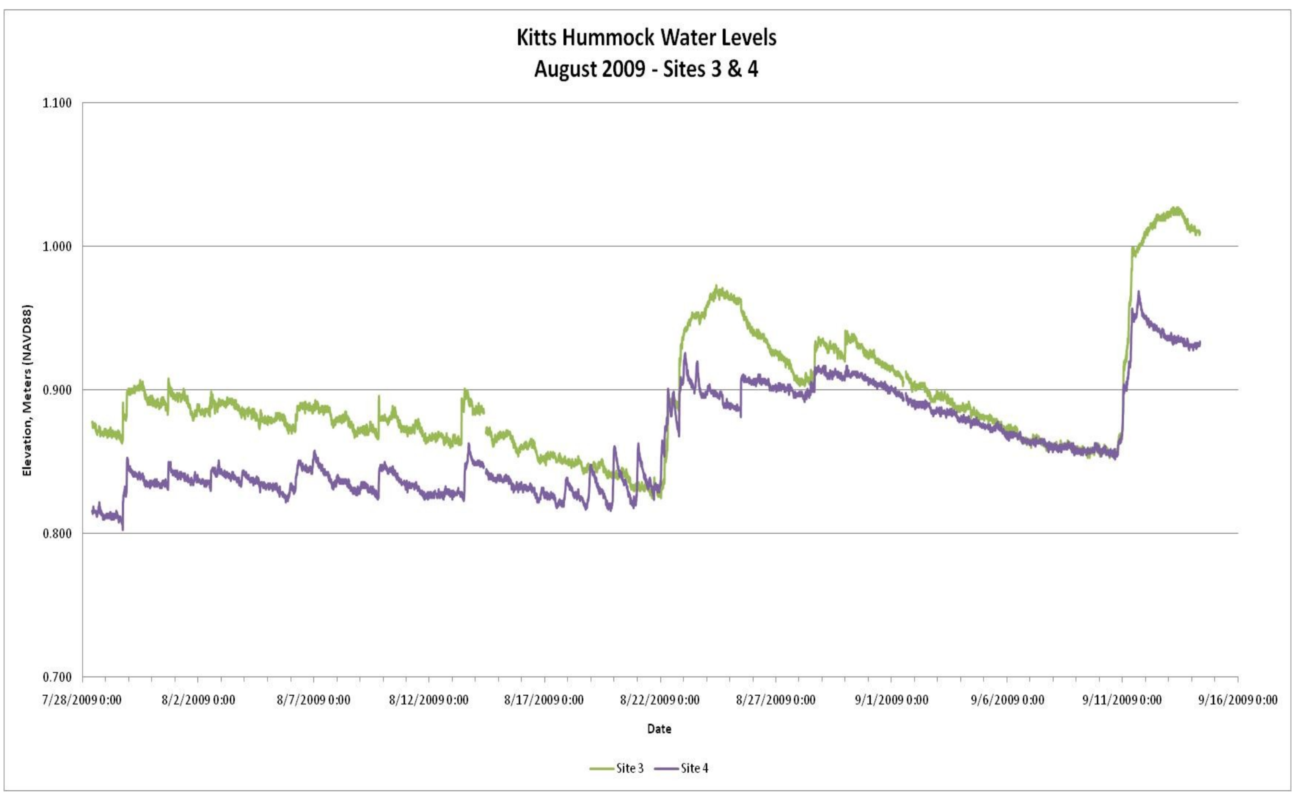


Figure 6. Water levels north/south of Kitts Hummock Road.

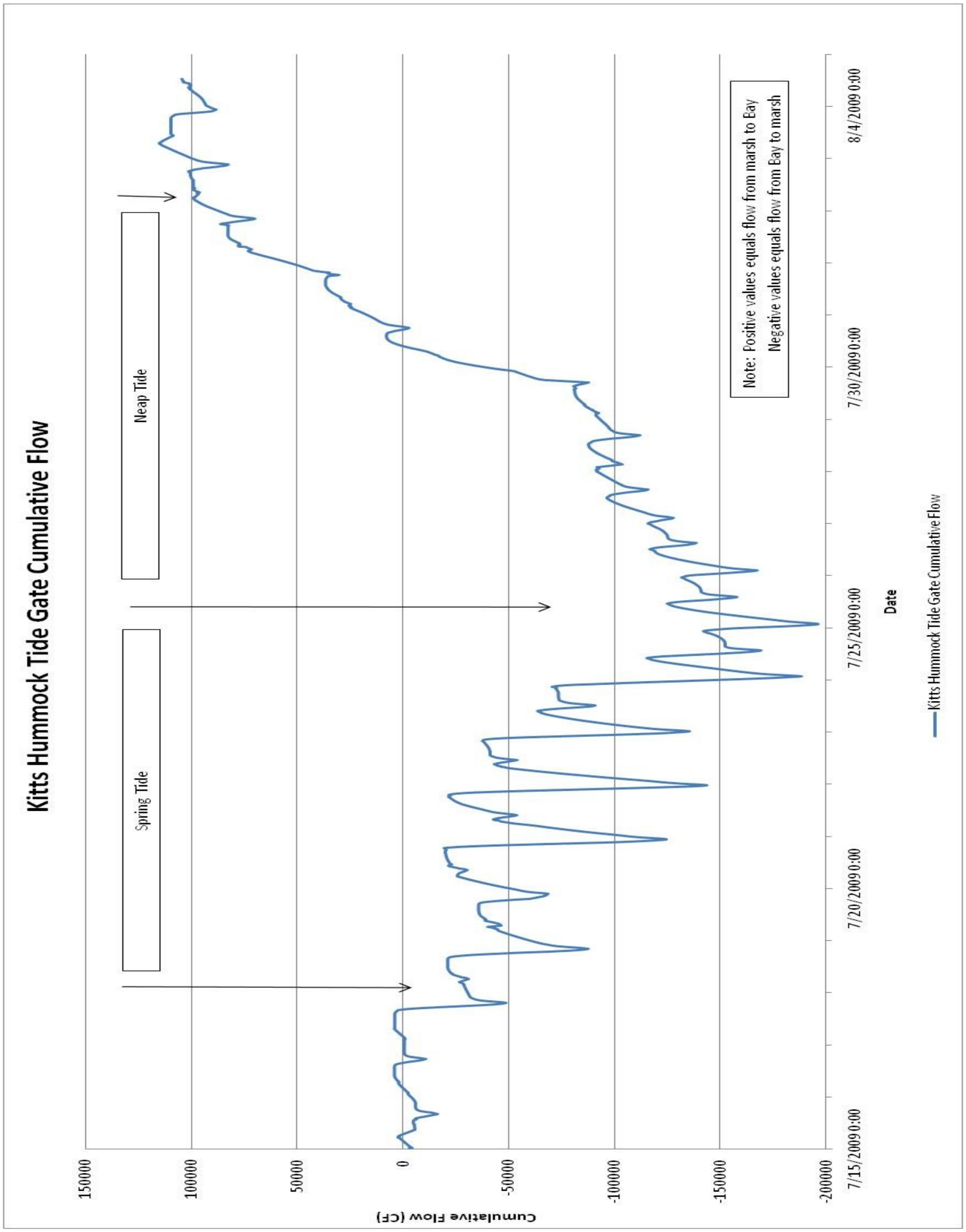
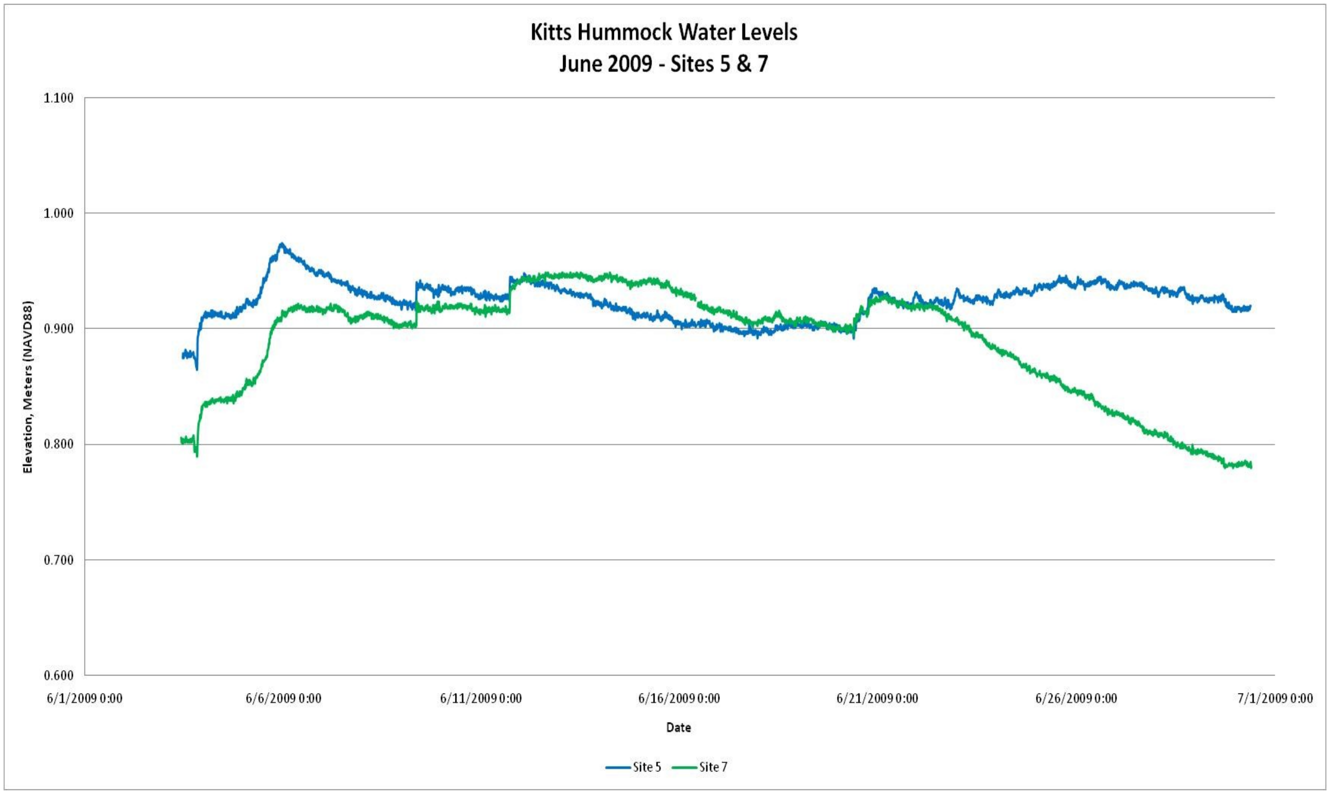


Figure 7. Cumulative Flow through the tide gate.



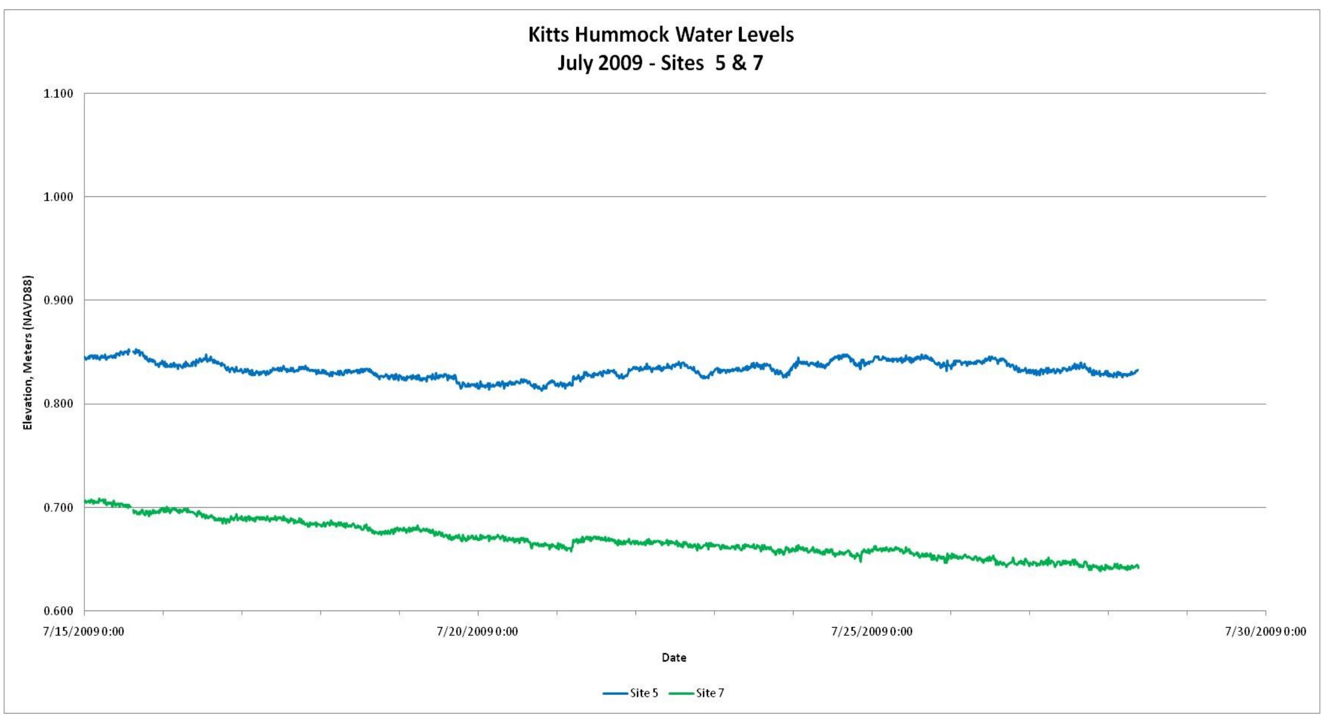


Figure 8. Water levels in June & July in SKHM (Site 5) and THWAI (Site 7).

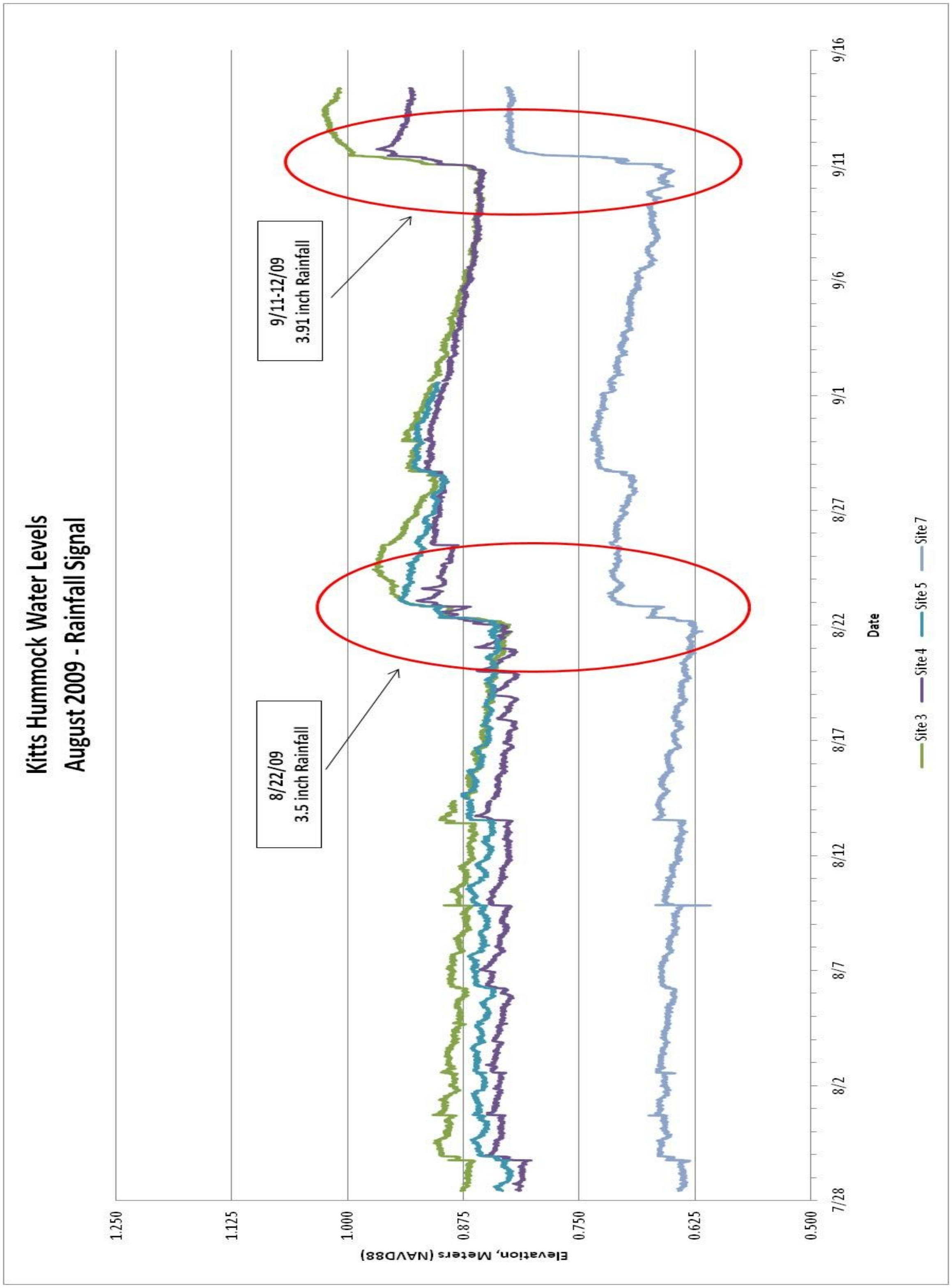


Figure 9. Rainfall induced changes in water level.

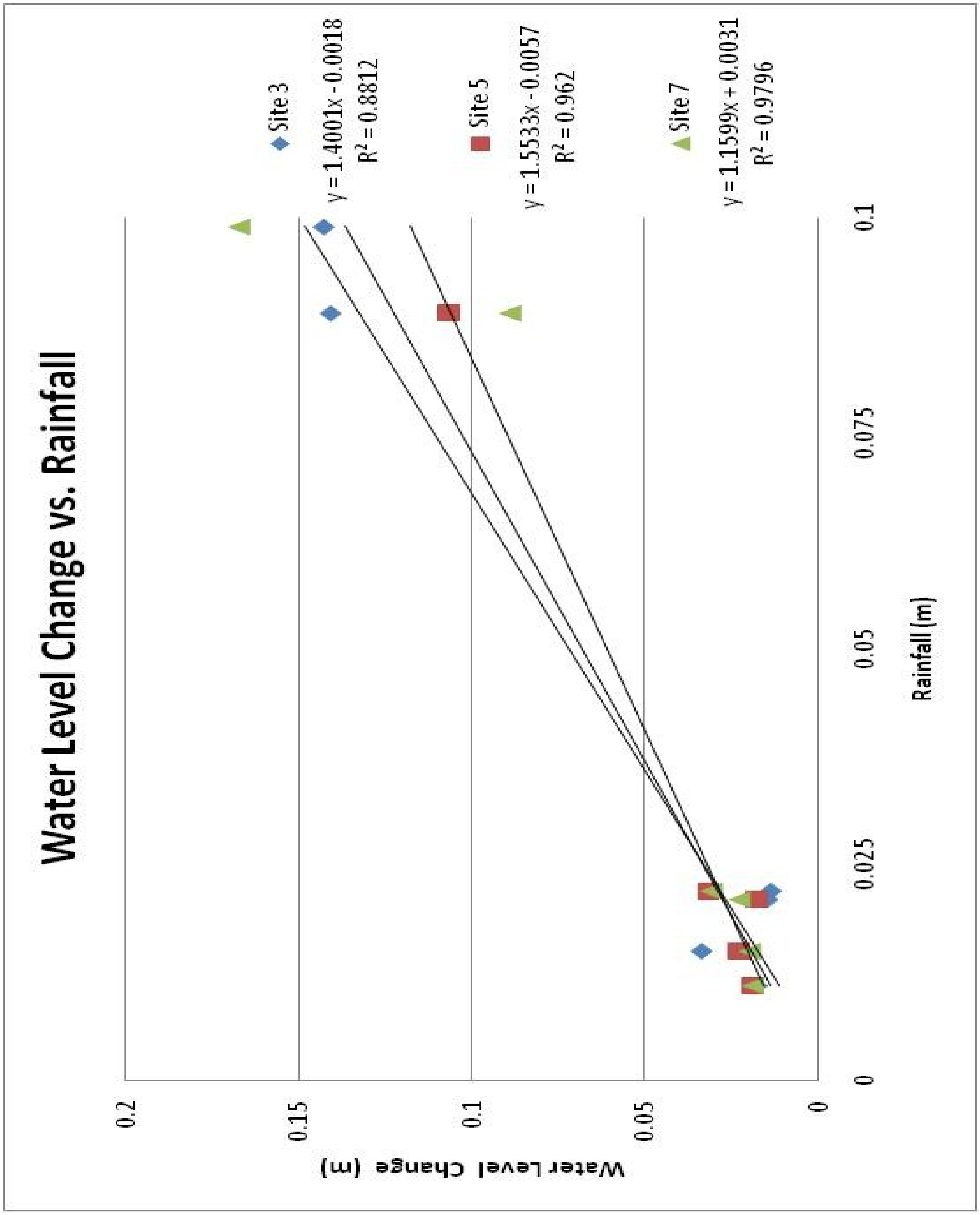


Figure 10. Analysis of water level change due to rainfall.

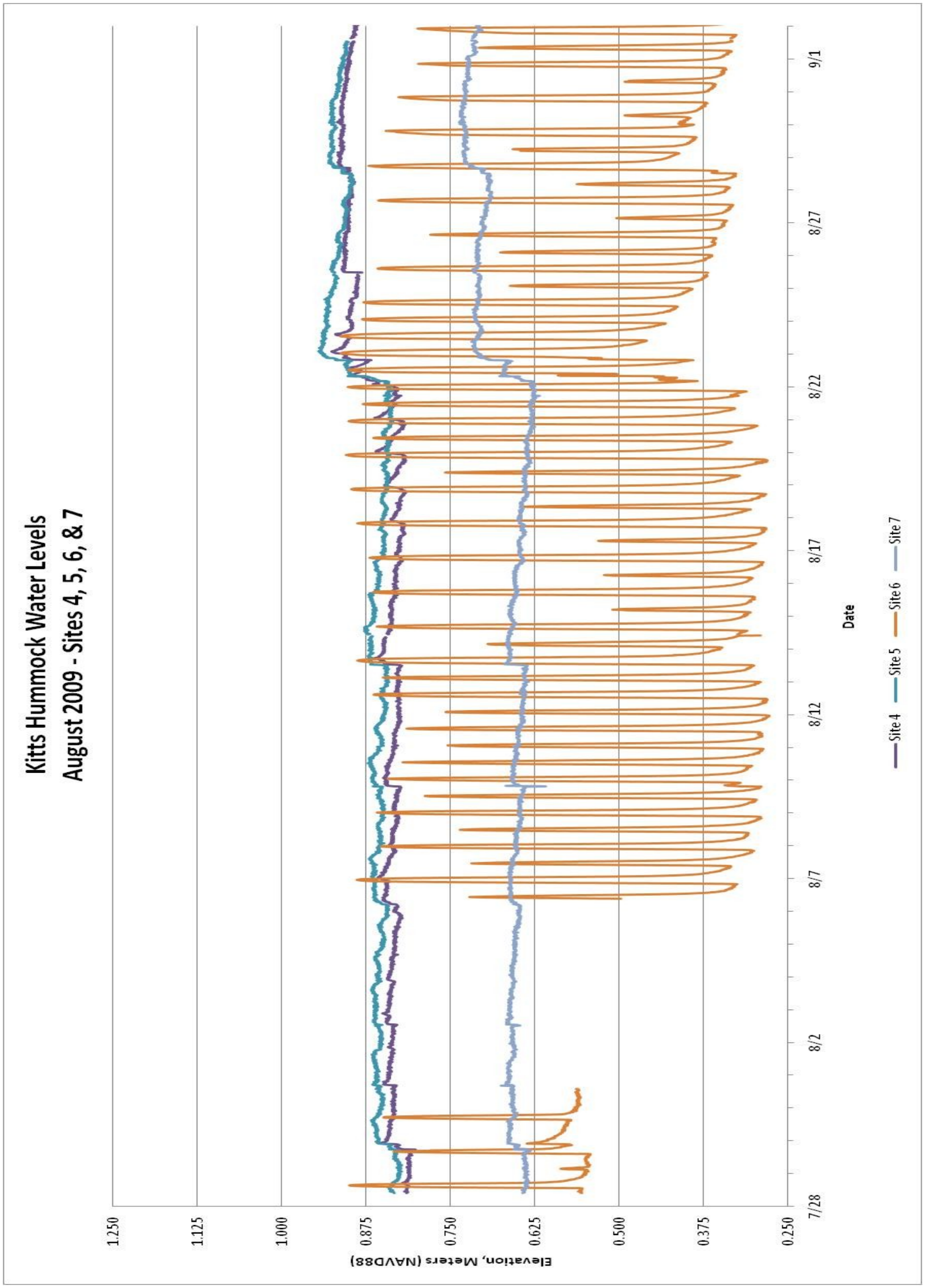


Figure 11. Water levels after South Bay Drive ditch maintenance.

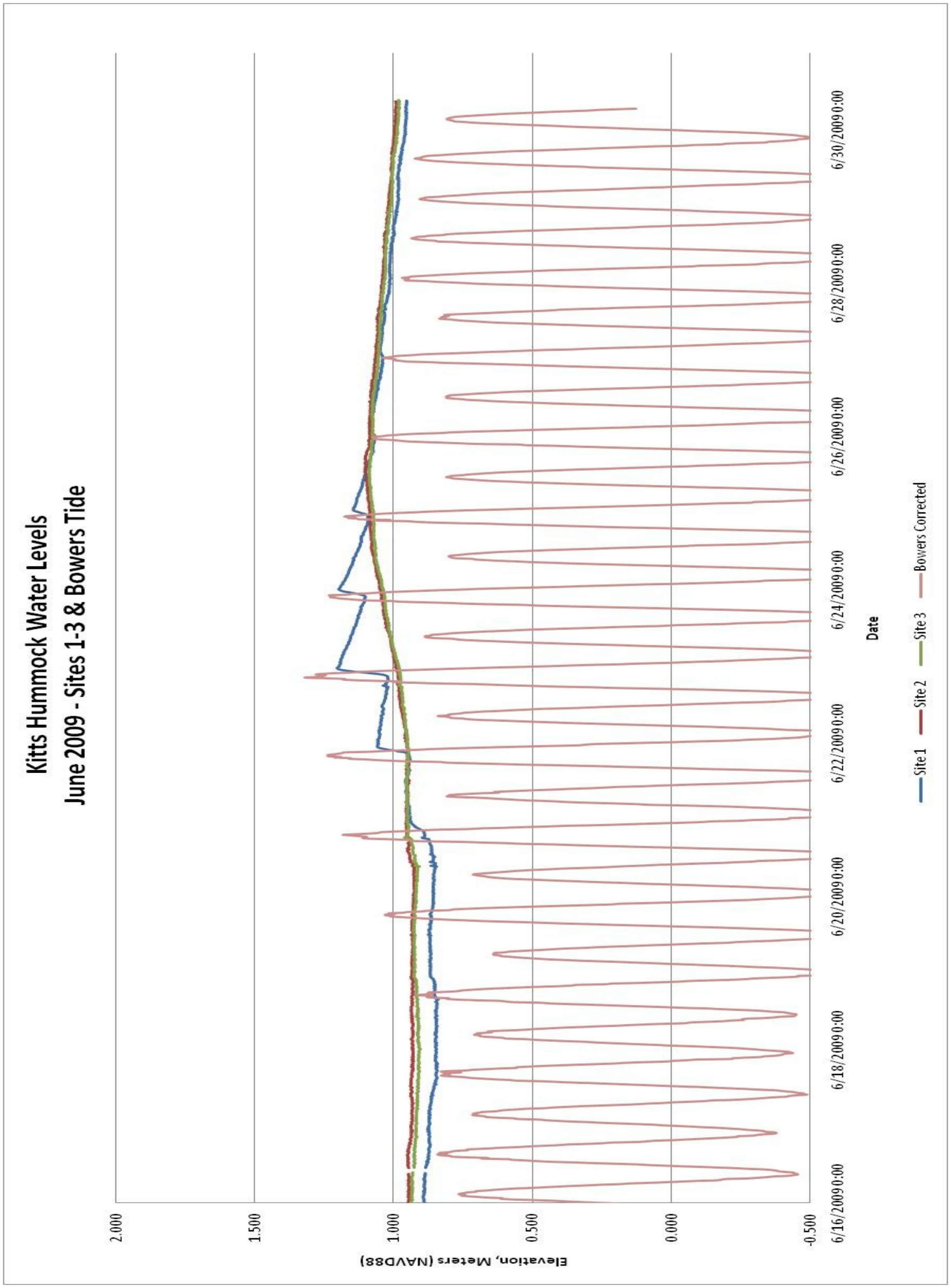


Figure 12. Water levels during extreme tides caused by coastal storms.

Date	Location	Water Level Change (in/day)
6/12-18	Site 1 Site 2 Site 5	-0.39 -0.95 -0.22
7/2-10	Site 1 Site 2 Site 5	-0.35 -0.71 -0.20

Table 1. Dry weather water level changes.